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1. I am a citizen of Japan residing at 24-5, Mejirodai 4-chome, Hachioji-shi, Tokyo, Japan.

2. To the best of my ability, I translated:

Japanese Patent Application No. 2003-097015

from Japanese into English and the attached document is a true and accurate English translation thereof.

3. I further declare that all statements made herein are true, and that all statements made on information and belief are believed to be true; and further that willful false statements and the like are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

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Ikuzo Tanaka

Ikuzo Tanaka

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Inventor	
Address	c/o Hitachi Metals Ltd., Casting Technology Research Laboratory 11, Kinugaoka, Mooka-shi, Tochigi-ken
Name	Koki Otsuka
Inventor	
Address	c/o Hitachi Metals Ltd., Casting Technology Research Laboratory 11, Kinugaoka, Mooka-shi, Tochigi-ken
Name	Seiichi Endo
Inventor	
Address	c/o Hitachi Metals Ltd., Casting Technology Research Laboratory 11, Kinugaoka, Mooka-shi, Tochigi-ken
Name	Takashi Hattori
Inventor	
Address	c/o Hitachi Metals Ltd., Casting Technology Research Laboratory 11, Kinugaoka, Mooka-shi, Tochigi-ken

Name	Masanori Hara	
Applicant		
Identification No.	000005083	
Name	Hitachi Metals, Ltd.	
Representative	Yoshihiro Honda	
Official Fee	Paid in Advance	
	010375	
	21,000	
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Japanese Patent Application No. 2003-097015

Specification

INTERNAL ENGINE PISTON AND ITS PRODUCTION METHOD

Claims:

1. An internal engine piston comprising a cast steel and formed by integral casting.

2. The internal engine piston according to claim 1, whose head portion, pin boss portion and skirt portion are formed by integral casting.

3. The internal engine piston according to claim 1 or 2, wherein it further comprises a cooling hollow portion, which is formed by integral casting.

4. The internal engine piston according to any one of claims 1 to 3, wherein said cast steel has an area ratio of sulfides containing at least one of Mn and Cr is 0.2-3.0% in said cast steel microstructure, and wherein a ratio of the number of sulfides each having a circularity of 0.7 or more to the total number of sulfides is 70% or more.

5. The internal engine piston according to any one of claims 1 to 4, wherein said cast steel has a matrix microstructure comprising a ferrite phase and a pearlite phase.

6. The internal engine piston according to claim 5, wherein said cast steel has a composition comprising, by mass, 0.55% and less of C, 2% and less of Si, 3% and less of Mn, 0.2% or less of S, and 0.5 % or less of at least one of Nb, V and Ti.

7. The internal engine piston according to any one of claims 1 to 4, wherein said cast steel has a matrix microstructure comprising a ferrite phase and a martensite phase, and wherein said austenite phase is less than 30%.

8. The internal engine piston according to claim 7, wherein said cast steel has a composition comprising, by mass, 0.5% or less of C, 2% or less of Si, 3% or less of Mn, 0.2% or less of S, 6% or less of Ni, 20% or less of Cr, 6% or less

of Cu, and 5% less of Nb.

9. The internal engine piston according to claim 7 or 8, wherein said cast steel has a composition comprising, by mass, 0.03-0.5% of C, 0.2-2.0% of Si, 0.3-3.0% of Mn, 0.05-0.20% of S, 0.5-6% of Ni, 6-20% of Cr, 1-6% of Cu, and 0.2-5% of Nb.

10. The internal engine piston according to any one of claims 7 to 9, wherein said cast steel comprises C, Ni and Nb in a range of $0.05 < (C\% + 0.15\ Ni\% - 0.10\ Nb\%) \leq 0.80$.

11. The internal engine piston according to any one of claims 5 to 10, wherein said cast steel comprises, by mass, at least one of 0.04% or less of Al, 0.04% or less of Mg and 0.04% or less of Ca.

12. The internal engine piston according to any one of claims 1 to 11, wherein said cast steel has a 0.2-% yield strength of 350 MPa or more and a Young's modulus of 140 GPa or more in a temperature range of 350°C to 500°C, and an average linear thermal expansion coefficient of $10\text{-}16 \times 10^{-6}/°C$ between room temperature and 500°C.

13. A method for producing the internal engine piston recited in claim 5 or 6, comprising casting said steel, holding it at 850°C or higher, and then air-cooling it.

14. The method for producing an internal engine piston according to any one of claims 7 to 10, wherein said cast steel is held at 450°C or higher after casting, and then air-cooled.

15. The method for producing an internal engine piston according to claim 14, wherein said cast steel is held at 1000°C or higher after casting, rapidly cooled, held at 450°C or higher, and then air-cooled.

DETAILED DESCRIPTION OF THE INVENTION

[0001]

Field of the Invention

The present invention relates to an internal engine piston suitable for automobile engines, particularly for diesel engines, etc., and its production method.

[0002]

Prior Art

The combustion temperatures and pressures of automobile engines have been becoming increasingly higher to plan the reduction of the environmental load such as NOx (nitrogen oxide), PM (particulate matter), etc., and speedup thereof has been advancing. Accordingly, in diesel engine pistons, spheroidal graphite cast iron having relatively high durability has recently become adopted in place of Aluminum alloys such as JIS AC8A, etc. having as low thermal and mechanical durability temperatures as about 350°C, and large thermal expansion (see, for instance, Patent Literature 1).

[0003]

On the other hand, there is an internal engine piston (hereinafter referred to simply "piston") comprising a head portion having a pin boss portion, and a skirt portion, which are produced separately and integrally assembled. Fig. 5 is a cross-sectional view showing an example of such piston 20. In a piston 20 shown in Fig. 5, the head portion 21 and the pin boss portion 24 are formed by a precipitation-hardened, forged ferrite-pearlite steel comprising, by weight, 0.32-0.45% of C, 0.4-0.9% of Si, 1.0-1.8% of Mn, 0.035% or less of P, 0.065% or less of S, and 0.06-0.15% of V, the balance being Fe, and the skirt portion 22 is formed by a light alloy such as aluminum, etc. It is described that such microstructure makes it possible to produce a piston at a lower cost than a conventional (DIN) $Fe_{bal}Cr_{42}Mo_4$ alloy (corresponding to JIS SCM440) (see, for

instance, Patent Literature 2). Incidentally, the piston 20 comprises a head portion 21 comprising a combustion chamber 25, a top surface 26 and an opening fringe (lip) 27 of the combustion chamber 25, a top land 28 positioned in the nearest to the combustion chamber 25 of circumference of the piston 20, ring grooves 29 for receiving piston rings, and a cooling hollow portion 23, in which oil is circulated to cool the combustion chamber 25. 20h denotes a distance (compression height) from a center of a hole for receiving the pin to the top surface 26.

[0004]

In addition, there is a piston comprising a head portion, a skirt portion and a pin boss portion, which are produced separately and integrally connected. Fig. 7 is a cross-sectional view showing a conventional example of such piston 30 comprising a head portion 31, a skirt portion 32 and a pin boss portion 34, which are produced separately and diffusibly connected. In Fig. 7, there is a disclosure that the piston 30 comprises the head portion 31 formed by a high strength material at a high temperature such as the heat-resisting steel, the skirt portion 32 formed by Nodular cast steel (that is, spheroidal graphite cast iron) excellent in slidability and the pin boss portion 34 formed by a high strength material such as nickel-chrome-molybdenum steel, and these three portions are diffusibly connected via connection faces M1, M2, thereby making it possible not only to achieve lightweight but also increase the connection strength (see, for instance, Patent Literature 3). Incidentally, in Fig. 7, 30 denotes a combustion chamber, 36 denotes a top surface, 37 denotes a lip, 38 denotes a top land, 39 denotes ring grooves, 33 denotes a cooling hollow portion, in which oil is circulated to cool the combustion chamber 35, and 30h denotes a compression height. The cooling hollow portion 33 is formed by connecting the head portion 31 and the pin boss portion 34 via the connection face M1.

[0005]

[Patent Literature 1]

JP 10-85924 (page 2, 1st column, lines 39-46).

[Patent Literature 2]
US Patent 5,136, 992 (column 2, lines 37-52).

[Patent Literature 3]
JP 7-293326 (page 3, 1st column, lines 1-7; and Fig. 1).

[0006]

Problems to be solved by the Invention

Heat load to the piston recently increases more, and, accordingly, high-temperature yield strength, high-temperature rigidity, thermal cracking resistance corresponding to the combustion temperature of 450-500°C in the piston are demanded. In addition, it must be necessary to have the low thermal expansion properties as similarly in the conventional piston. Increasing in the number of revolutions of the engine also, the reduce in inertia at the time of reciprocation of the piston due to light weight thereof by making the main part wall thickness of the piston thinner and the compaction of engine room by making the compression height smaller are demanded. Furthermore, the integral formulation including the cooling hollow portion essential in the piston for diesel engines conventionally is demanded in a low production cost.

[0007]

However, when a piston comprising spheroidal graphite cast iron as disclosed in the patent literature 1 is made thinner and used in a temperature range from room temperature to 450-500°C, there occurs inner oxidation originated from graphite by repeated combustions at high temperatures, which develops to thermal cracking. Furthermore, the thermal cracking is promoted with deformation and decrease in strength by exposing the piston in this temperature range for a long time to cause the deterioration of the material by accelerating the decomposition of pearlite. For instance, when a piston comprising spheroidal graphite cast iron is used in a direct-injection model

engine, there likely generates cracking in the combustion chamber and nearby lips closer thereto to be elevated to high temperatures, and when the piston is made thinner, there occur problems such as blowby, wear, seizure, or breakage, thereby making it likely that the engine performance is deteriorated.

[0008]

Also, as disclosed in the previous patent literature 2, although a piston 20 comprising a head portion 21 formed by forged steel shown in Fig. 5 thereof is excellent in high-temperature rigidity, it is impossible to produce the piston comprising the cooling hollow portion 23 integrally by one step in the forging method. In addition, as well as the Patent Literature 2, in the forging method, there are many production steps such as a forging process, a step of machining the cooling hollow portion 23, a step of fixing a cover f to the hollow portion, etc., and the step of machining the cooling hollow portion 23 involves a specific cutting machining of a deep groove, and it needs the step of assembling the divided head portion 21, the skirt portion 22, and the like, resulting in a high production cost. Also, in the piston produced by a forging method, sulfides and other inclusions a are present as a state of fibers extending in a main deformation direction, that is, along a metal flow line during forging as shown in a metal microstructure photomicrograph (magnification: 400 times) shown in Fig. 6, so that thermal cracking is likely to occur in the lip 27 of an opening end of a combustion chamber 25, when used under high thermal load in a temperature range from room temperature to 450-500°C. Above all, there arises a problem such that when improving the machinability by forming sulfides in the matrix microstructure for the purposes of shortening the period of time for machining step and of using a cheap cutting tool, the tendency of generating the thermal cracking increases more due to the increase of fiber like sulfides. Further, because in the piston ring 20 formed by forged steel disclosed in the patent literature 2, it needs at least a space, into which a bite for

machining the cooling hollow portion 23 is introduced, it inevitably has a large compression height 20h, thereby making it impossible to achieve lightweight, resulting in difficulty in size reduction of the engine room.

[0009]

Also, as disclosed in the previous Patent Literature 3, because a piston 30 comprising a head portion 31, a skirt portion 32 and a pin boss portion 34 shown in Fig. 7 thereof are diffusibly connected, it requires many parts and many steps, resulting in increase in production cost. In addition, although the head portion 31 is formed by forged steel, the skirt portion 32 is formed by Nodular cast steel (that is, spheroidal graphite cast iron) and the pin boss portion 34 is formed by a high strength material such as nickel-chrome-molybdenum steel, the connection portions connecting diffusibly these respective main constitutional components are not sufficient in high-temperature yield strength in a temperature range of 450-500°C, thereby likely destroying the thermal cracking resistance, and, as a result, it causes a problem in the reliability of the connection portions.

[0010]

In addition, although as the connection means of the main constitutional components, welding and a method by friction pressure welding are known also, it is difficult to secure the connection strength to use in a temperature range from room temperature to 450-500°C as compared with the diffusible connection described above. In addition, when the connection portions are formed in the cooling hollow portion, there are produced a fin at an inner wall side of the cooling hollow portion. Because the cooling hollow portion is closed except an opening portion to circulate oil, it is impossible to completely remove the fin of the inner wall side, and the cooling hollow portion becomes small due to the remaining fin, which disturbs a flow of the oil and decreases the cooling efficiency of the combustion chamber, and the fin pealed or fell off during the use thereof promotes the wear in cylinder liner and piston

ring, thereby likely destroying engine performance.

[0011]

In view of the above problems, the present invention has been made, and, accordingly, an object of the present invention is to provide an internal engine piston having high high-temperature yield strength, high-temperature rigidity, thermal cracking resistance and low thermal expansion properties such that it can be used in a temperature range from room temperature to 450-500°C suitable for automobile engines, particularly for diesel engines, etc. and a method for producing such an internal engine piston.

[0012]

Means for solving the Problems

[0013]

The internal engine piston of the present invention comprises cast steel, and formed by integral casting. By appropriately selecting the material from cast steel, it is possible to provide a piston having high high-temperature yield strength, high-temperature rigidity, thermal cracking resistance and low thermal expansion properties when used even in a temperature range from room temperature to 450-500°C, so that there hardly generates cracking in the combustion chamber and nearby lips closer thereto to be elevated to high temperatures. In addition, cast steel is higher in high-temperature rigidity as compared with spheroidal graphite cast iron, and, accordingly, when the piston is made thinner, there hardly occur problems such as biowby, wear, seizure, or breakage, thereby not making it that the engine performance is deteriorated. Also, it is possible to make the piston thinner and lightweight for reducing inertia at the time of reciprocation of the piston. Further, the formulation by integral casting not only makes the connection of main constitutional components to each other unnecessary, thereby making it possible to reduce the working cost as a near-net shape, and reduces the process steps, resulting in the

decrease in production cost, but also solves the problem of the reliability poor in high-temperature yield strength and connection strength of the connection portions.

[0014]

In addition, the formulation of the piston by integral casting including main constitutional components of the piston such as a head portion, a pin boss portion and a skirt portion can produce a piston usable for gasoline engine which need no cooling hollow portion.

[0015]

In addition, the formulation of the piston by integral casting including the cooling hollow portion makes it possible to provide a piston suitable for diesel engines. That is, as compared with the piston formed by a forging method, it does not need the steps of specific cutting for machining the cooling hollow portion, a step of fixing a cover f to the hollow portion, etc., resulting in decrease in the process steps to lower production cost, and also, because the formulation of the piston by integral casting does not need a space, into which a bite for machining the cooling hollow portion is introduced, it can have a low compression height, so that it is possible to achieve lightweight of the piston and compactness of the engine room. Further, there is no likelihood to destroy engine performance due to the fin remaining in the cooling hollow portion as in the piston formed by the connection means.

[0016]

In the internal engine piston of the present invention, the cast steel having an area ratio of sulfides containing at least one of Mn and Cr is 0.2-3.0% in the cast steel microstructure, and a ratio of the number of sulfides each having a circularity of 0.7 or more to the total number of sulfides is 70% or more. When the cast steel usable for the piston member having high high-temperature yield strength, high-temperature rigidity, thermal cracking resistance and low thermal expansion properties used in a temperature range from room

temperature to 450-500°C has an area ratio of sulfides containing at least one of Mn and Cr of 0.2-3.0% in the cast steel microstructure and a ratio of the number of sulfides each having a circularity of 0.7 or more to the total number of sulfides of 70% or more, the thermal cracking resistance is not destroyed. In addition, the internal lubrication action possessed by sulfides makes it possible to reduce the cut resistance and extend the life of the cutting tool, thereby producing effect for improving the machinability. On the other hand, when an area ratio of sulfides containing at least one of Mn and Cr exceeds 3.0% in the cast steel microstructure and a ratio of the number of sulfides each having a circularity of 0.7 or more to the total number of sulfides is less than 70%, they lower not only the thermal cracking resistance but also the toughness of the cast steel. Therefore, an area ratio of sulfides containing at least one of Mn and Cr is 0.2-3.0% in the cast steel microstructure, and a ratio of the number of sulfides each having a circularity of 0.7 or more to the total number of sulfides is 70% or more.

[0017]

In the internal engine piston of the present invention, the cast steel preferably contains the sulfides above and has a matrix microstructure comprising a ferrite phase and a pearlite phase, and further the cast steel preferably has a composition comprising, by mass, 0.55% and less of C, 2% and less of Si, 3% and less of Mn, 0.2% or less of S, and 0.5 % or less of at least one of Nb, V and Ti. A cylinder liner member as a mating member contacting with the sliding piston is almost made of flake graphite cast iron such as FC250 or FC300, and the raw material of the piston is required to be a linear thermal expansion coefficient substantially equal to that of a cylinder liner. This is aimed at keeping clearance between the piston and the cylinder liner appropriately, and when a matrix microstructure of the piston member comprises an austenite phase and a pearlite phase, the linear thermal expansion

coefficient thereof is to be substantially equal to that of the cylinder liner, thereby making it possible to secure the clearance between the piston and the cylinder liner properly even when used in a temperature range from room temperature to 450-500°C, so that the engine performance is not destroyed by blowby and wear, seizure or breakage. Reasons for limiting the composition will be discussed later.

[0018]

In the internal engine piston of the present invention, the cast steel preferably contains the sulfides above and has a matrix microstructure comprising a ferrite phase and a martensite phase, where the austenite phase is less than 30%. When a matrix microstructure of the piston member comprises a ferrite phase and a martensite phase, it is possible to secure high-temperature yield strength even when used in a temperature range from room temperature to 450-500°C. In addition, as described above, although the raw material of the piston is required to be a linear thermal expansion coefficient substantially equal to that of the cylinder liner, when an area ratio of the austenite phase, which increases the linear thermal expansion coefficient, is less than 30%, the linear thermal expansion coefficient thereof is to be substantially equal to that of the cylinder liner, thereby making it possible to secure the clearance between the piston and the cylinder liner, so that the engine performance is not destroyed.

[0019]

Further, the composition of the above cast steel having a matrix microstructure comprising a ferrite phase and a martensite phase, where the austenite phase is less than 30% comprises preferably, by mass, 0.5% or less of C, 2% or less of Si, 3% or less of Mn, 0.2% or less of S, 6% or less of Ni, 20% or less of Cr, 6% or less of Cu, and 5% less of Nb, and more preferably comprises, by mass, 0.03-0.5% of C, 0.2-2.0% of Si, 0.3-3.0% of Mn, 0.01-0.20% of S, 0.5-6% of Ni, 6-20% of Cr, 1-6% of Cu, and 0.2-5% of Nb.

The cast steel most preferably comprises the above C, Ni and Nb in a range of $0.05 < (C\% + 0.15\ Ni\% - 0.10\ Nb\%) \leq 0.80$. Reasons for limiting the composition and the range of C, Ni and Nb above will be discussed later.

[0020]

In the internal engine piston of the present invention, the cast steel preferably comprises, by mass, at least one of 0.04% or less of Al, 0.04% or less of Mg and 0.04% or less of Ca. Reasons for limiting the composition will be discussed later.

[0021]

In addition, the cast steel preferably has a 0.2-% yield strength of 350 MPa or more and a Young's modulus of 140 GPa or more in a temperature range of 350°C to 500°C, and an average linear thermal expansion coefficient of 10-16 x 10^{-6}/°C between room temperature and 500°C.

[0022]

The combustion temperature of 450-500°C at which the piston is exposed in the engine is such a temperature that cannot be applied in the piston comprising aluminum alloy or spheroidal graphite cast iron. To use in such a high temperature range, it is necessary for the piston to combine high-temperature yield strength, high-temperature rigidity, thermal cracking resistance and low thermal expansion coefficient, and it is desirable to satisfy the following properties as shown below at the same time. That is, a 0.2-% yield strength is 350 MPa or more and a Young's modulus is 140 GPa or more in a temperature range of 350°C to 500°C, and an average linear thermal expansion coefficient is 10-16 x 10^{-6}/°C between room temperature and 500°C. When the yield strength in a temperature range of 350°C to 500°C is 350 MPa or more, it is possible to not only secure the high-temperature yield strength in a temperature range of 450°C to 500°C but also secure its thermal cracking resistance by a synergistic effect with a small linear thermal expansion

coefficient thereof as described below. Besides, it is possible to make lightweight by being made it thinner to be equal to that of the piston comprising aluminum alloys.

[0023]

In addition, it is possible to secure its high-temperature rigidity by making a Young's modulus, which is an indicator showing the high-temperature rigidity of the piston, 140 MPa or more in a temperature range of 350°C to 500°C at the same time, so that the shape dimensions of piston precisely finishing machined is maintained, thereby destroying the engine performance. In addition, it is possible to make lightweight by being made it thinner.

[0024]

In addition, the average linear thermal expansion coefficient of the piston is to be substantially equal to an average linear thermal expansion coefficient of a cylinder liner made of flake graphite cast iron (13.1 x 10^{-6}/°C in a temperature range of 20-480°C) by making an average linear thermal expansion coefficient between room temperature and 500°C, which is an indicator showing the low thermal expansion properties, 10-16 x 10^{-6}/°C at the same time, thereby properly keeping clearance between the piston and the cylinder liner small and securing the clearance appropriately when used in a temperature range from room temperature to 450-500°C, and thus reducing oil consumption for lubrication.

[0025]

Reasons for limiting the composition of raw materials usable for the internal engine piston of the present invention will be explained below.

[0026]

(1) C: 0.55% or less; or C: 0.5% or less, preferably 0.03-0.5%

With respect to the above cast steel of claims 5 to 6 having a matrix microstructure comprising an austenite phase and a pearlite phase (hereinafter

referred to simply as "α-P cast steel"), C forms a cementite in the pearlite phase and forms carbides with elements such as Nb, V, Ti, etc., thereby producing effect for securing a high-temperature yield strength, but when C exceeds 0.55%, the ferrite phase decreases and the amount of the pearlite phase increases, so that the thermal cracking resistance is deteriorated, thereby resulting in the decrease in its toughness, and, accordingly, C is 0.55% or less. In the piston which suffers from a high load stress, the C in the α-P cast steel is preferably 0.35-0.55% to secure the high-temperature yield strength.

[0027]

On the other hand, with respect to the above cast steel of claims 7 to 10 having a matrix microstructure comprising a ferrite phase and a martensite phase, where the austenite phase is less than 30% (hereinafter referred to simply as "δ-M cast steel"), C is combined with Nb, thereby acting to prevent crystal grains from coarsing thereof. In addition, C makes it possible to lower a solidification temperature, and improves the castability of a melt, namely improves the flowability of a melt during casting, etc. This effect is, for instance, extremely important when a thin piston is cast, and C should be added thereto in good balance with the Nb content as described later. However, when C exceeds 0.5%, there remains much amount of an austenite phase to decrease hardness, thereby making it impossible to achieve high-temperature yield strength, high-temperature rigidity and wear resistance and moreover increasing the amount of Nb balancing with the C content, resulting in high cost. Accordingly, in the δ-M cast steel, C is 0.5% or less, preferably 0.03-0.5%, more preferably 0.04-0.5%.

[0028]

(2) Si: 2% or less, preferably 0.2-2.0%

In the α-P cast steel, Si has a function as a deoxidizer of a melt, securing castability by preventing gas defects due to a CO gas, etc. On the

other hand, in the δ-M cast steel, Si carries a role to protect and strengthen a passive film formed mainly on the Cr, in addition to the deoxidization action as described above, improving corrosion resistance. However, in either the α-P cast steel or the δ-M cast steel, when Si exceeds 2%, the thermal shock resistance and machinability decrease. Accordingly, Si is 2% or less, preferably 0.2-2.0%, more preferably 0.2-1.5%.

[0029]

(3) Mn: 3% or less, preferably 0.3-3.0%

Mn deoxidizes a melt and forms non-metallic inclusions, thereby improving machinability. Particularly, in the α-P cast steel it produces effect for securing the strength by a normalizing treatment described below. However, in either the α-P cast steel or the δ-M cast steel, when Mn exceeds 3%, the toughness decreases. Accordingly, Mn is 3% or less, preferably 0.3-3.0%, more preferably 0.3-1.0%.

[0030]

(4) S: 0.2% or less; or S: 0.2% or less, preferably 0.01-0.2%

S has functions of forming sulfides with Mn and Cr for improving the machinability of the cast steel due to their internal lubrication action. However, when S exceeds 0.2%, excess S-containing inclusions are formed, resulting in the deterioration of the thermal cracking resistance. To improve the machinability without deteriorating the thermal cracking resistance, S is 0.2% or less. In the α-P cast steel, S is preferably 0.005-0.2%. In the δ-M cast steel, S is preferably 0.01-0.2%, more preferably 0.005-0.15%.

[0031]

(5) Ni: 6% or less, preferably 0.5-6%

Ni strengthens the matrix microstructure in the δ-M cast steel, improving high-temperature yield strength and corrosion resistance. However, when Ni exceeds 6% to be contained much amount thereof in the cast steel, an

Ms point thereof falls in lower than room temperature, thereby leaving too much of austenite phase to cause lack of high-temperature yield strength. Accordingly, the content of Ni is 6% or less, preferably 0.5-6%, more preferably 0.5-5%.

[0032]

(6) Cr: 20% or less, preferably 6-20%

Cr improves, in the δ-M cast steel, high-temperature yield strength and secures the flowability of a melt during casting. In addition, Cr forms a stable dense passive film excellent in coherency on a surface of the matrix, improving corrosion resistance. On the other hand, when Cr exceeds 20%, there generate slag during casting, thereby likely inviting casting defects such as different substance-catching defect, etc. Accordingly, Cr is 20% or less, preferably 6-20%, more preferably 12-18%.

[0033]

(7) Cu: 6% or less, preferably 1-6%

Cu produces the similar effect in the δ-M cast steel as that of Ni, strengthening a matrix microstructure, thereby making it possible to improve high-temperature yield strength and corrosion resistance. In addition, by an aging treatment described below, Cu deposits on the matrix microstructure, thereby making it possible to more improve high-temperature yield strength. Accordingly, Cu is 6% or less, preferably 1-6%, more preferably 2-4%.

[0034]

(8) Nb: 5% or less, preferably 0.2-5%

Nb is combined with C in the δ-M cast steel to form fine Nb carbides (NbC), thereby increasing high-temperature yield strength and preventing them from coarsening their crystal grains. However, when Nb exceeds 5%, there generate slag during casting, thereby likely decreasing machinability due to NbC. Accordingly, Nb is 5% or less, preferably 0.2-5%, more preferably

0.2-3.5%. In addition, because IVa and Va elements such as Ti, Zr, Hf, V, Nb and Ta in addition to Nb are combined with C to decrease the amount of C in the austenite phase and capable of increasing the amount of C effective to the flowability of a melt during casting so as to be replaceable with Nb, these elements may be used in place of Nb or in combination with Nb.

[0035]

(9) At least one of Nb, V and Ti: 0.5% or less

Nb, V and Ti have a function to strengthen the pearlite by forming their carbides in the α-P cast steel. However, even when the total amount of these elements exceeds 0.5%, there is no increase in their effect, thereby rather decreasing thermal cracking resistance and deteriorating toughness. Accordingly, at least one of Nb, V and Ti: 0.5% or less.

[0036]

(10) C, Ni and Nb being [$0.05 < (C\% + 0.15\ Ni\% - 0.10\ Nb\%) \leq 0.80$]

To cast a piston at a low cost, inexpensive raw materials should be used. Some scraps as raw materials should be cast with a high C content to secure castability such as melt flowability, etc., during casting. In the δ-M cast steel, a larger C content may lower an Ms point, leaving too much austenite at room temperature, thereby failing to obtain high-temperature yield strength and high-temperature rigidity. By restricting Nb functioning to form NbC, lower a C content in an austenite, and thus prevent the lowering of the Ms point of the matrix, and Ni lowering the Ms point to a range of $0.05 < (C\% + 0.15\ Ni\% - 0.10\ Nb\%) \leq 0.80$, the desired high-temperature yield strength and high-temperature rigidity can be obtained.

[0037]

(11) At least one of Al: 0.04% or less, Mg: 0.04% or less and Ca: 0.04% or less being contained

Al, Mg and Ca may be added, because they are effective as

deoxidizers of a melt, functioning to form and finely disperse nuclei of sulfides effective for machinability. On the other hand, if they are contained excessively they remain in the matrix microstructure as non-metallic inclusions, decreasing thermal cracking resistance. Accordingly, at least one of Al: 0.04% or less, Mg: 0.04% or less and Ca: 0.04% or less being contained, if necessary.

[0038]

In addition, besides the elements described above, in such a range that does not deteriorate castability, machinability and wear resistance, to improve high-temperature yield strength, by mass, 5.0% or less of Mo, 3.0% or less of W, 0.05% or less of B, 0.1% or less of N, 3.0% o less of Co, 0.05% or less of Ti, and 0.05% or less of V can be added thereto, and also to improve machinability and seizure resistance, by mass, at least one of 2.0% or less of Se and 0.1% or less of Bi can be added thereto.

[0039]

The production method of the present invention comprises the steps of subjecting the cast steel described above (α-P cast steel) comprising the sulfides and having a matrix microstructure comprising a ferrite phase and a pearlite phase to casting, after casting, holding it at 850°C or higher, and then air-cooling it. Because an as-cast piston may have different solidification and cooling speeds depending on its portions due to product shapes, mold designs, mold shapes, etc., it is preferable to homogenize the material by a heat treatment, thereby adjusting its wear resistance, hardness and mechanical properties. In this case, a mixed microstructure of proeutectoide ferrite and dense pearlite can be formed by a normalizing treatment which comprises holding the cast steel at 850°C or higher after casting, and air-cooling it, thereby securing strength and wear resistance necessary for the piston. When the heating temperature is lower than 850°C, complete austenitization does not occur. To austenitize the entire microstructure, heating should be preferably 850°C or higher. The heating-temperature-holding time may vary depending on the size, shape, etc. of

the piston, but it may be 0.5 hours or longer for small pistons, and 1 hour or longer for large pistons.

[0040]

The production method of the present invention comprises the steps of subjecting the cast steel described above (δ-M cast steel), which comprises the sulfides and has a matrix microstructure comprising a matrix microstructure comprising a ferrite phase and a martensite phase, where the austenite phase is less than 30%, to casting, after casting, either holding it at 450°C or higher, and then air-cooling it, or preferably holding it at 1000°C or higher, rapidly cooling it, holding it at 450°C or higher, and then air-cooling it. Because the piston is subjected to engine-performance-deteriorating problems such as blowby, wear, seizure and breakage when permanent deformation occurs due to the change of a material during use, the change of a material should be preferably made as small as possible in advance. For this purpose, it is effective to stabilize the material by holding it at a temperature higher than the temperature of using the piston. Specifically, it is preferable to conduct an aging treatment after casting, which comprises holding the cast piston at 450°C (piston-using temperature) or higher and air-cooling it. Moreover, when a solution treatment comprising holding it at 1000°C or higher after casting and rapidly cooling it is conducted before this aging treatment, brittle carbides (for instance, Cr carbides) in the material are more preferably dissolved in the matrix, securing toughness and ductility. Incidentally, the heating-temperature-holding time in the solution treatment and the aging treatment may vary depending on the size, shape, etc. of a piston, but it may be 0.5 hours or longer for the former and 2 hours or longer for the latter in a small piston, and 1.5 hours or longer for the former and 4 hours or longer for the latter in a large piston.

[0041]

EMBODIMENTS IN WORKING OF THE INVENTION

Embodiments in working of the invention will be explained in further detail below.

(Production of samples)

Table 1 shows chemical compositions (% by mass) and (C% + 0.15Ni% - 0.10Nb%) of the respective samples to measure high-temperature yield strength, high-temperature rigidity, thermal cracking and low thermal expansion resistance, and the samples of Examples 1-10 were made of the δ-M cast steel within the composition range of the present invention, the samples of Examples 1-13* were made of α-P cast steel within the composition range of the present invention, the samples of Comparative Examples 1-4 were made of stainless steel, and the samples 5 and 6 were made of carbon steel, in addition, Conventional Example 1 used spheroidal graphite cast iron (JIS FCD 600), and Conventional Example 2 used forged steel disclosed in the Patent Literature 2.

[0042]

In Table 1, each cast steel of Examples 1-10, and Example 11-13*, and Comparative Examples 1-6 was melted in a 100-kg, high-frequency furnace with a basic lining, poured into a ladle at 1550°C or higher, and immediately poured into a one-inch Y-block at 1500°C or higher. Each cast steel of Examples 1-10 (other than Example 5*) was subjected to a solution treatment comprising holding it at 1000-1200°C for 1 hour after casting and rapidly cooling it, followed by an aging treatment comprising holding it at 550-630 for 2-4 hours and air-cooling it, to provide a sample. Each cast steel of Examples 11-13 (other than Example 13*) was subjected to a normalizing heat treatment comprising holding the cast steel at 850-1000°C for 1 hour after casting, and then air-cooling it, to provide a sample.

[0043]

On the other hand, the sample of Conventional Example 1 was produced by melting a spheroidal graphite cast iron (corresponding to JIS FCD

600) in a 100-kg, high-frequency furnace with an acidic lining, conducting a spheroidizing treatment by a sandwiching method using Fe-75% Si and Fe-Si-4% Mg during pouring the melt into a ladle at 1500°C or higher, conducting a secondary inoculation with Fe-75% Si immediately before pouring from the ladle, and pouring the melt into a one-inch Y-block.

[0044]

Also, the sample of Conventional Example 2 made of cast steel having a composition corresponding to the forged steel piston disclosed in the Patent Literature 2 was produced by forming an ingot by vacuum melting, forging the ingot at 1100°C, and conducting a normalizing heat treatment from 950°C.

[0045]

Table 1

Chemical Composition (% by mass)

No(1)	C	Si	Mn	S	Ni	Cr	Cu	Nb	V	Ti	Others	C% +0.15Ni - 0.10Nb%	Heat Treatment
Ex. 1	0.07	0.60	0.41	0.023	4.19	16.10	2.90	0.37	0.008	0.004	Al: 0.021	0.66	Yes
Ex. 2	0.06	0.65	0.47	0.050	3.94	16.60	3.00	0.31	0.008	0.003	-	0.62	Yes
Ex. 3	0.05	0.55	0.47	0.063	4.58	14.50	3.20	0.29	0.007	0.005	-	0.71	Yes
Ex. 4	0.05	0.65	0.48	0.128	3.95	16.90	3.00	0.31	0.008	0.007	-	0.61	Yes
Ex. 5	0.05	0.65	0.48	0.200	3.95	16.90	3.00	0.31	0.012	0.005	-	0.61	Yes
Ex. 5*	0.05	0.65	0.48	0.200	3.95	16.90	3.00	0.31	0.010	0.005	-	0.61	No
Ex. 6	0.11	0.56	0.48	0.060	4.03	16.10	3.00	0.30	0.008	0.004	-	0.68	Yes
Ex. 7	0.12	0.58	0.47	0.061	3.89	16.10	2.90	1.00	0.008	0.005	-	0.60	Yes
Ex. 8	0.29	0.57	0.47	0.066	5.00	16.46	3.00	2.47	0.009	0.008	Mg: 0.032	0.79	Yes
Ex. 9	0.18	0.56	0.48	0.060	3.76	16.37	3.00	1.59	0.008	0.005	Ca: 0.034	0.59	Yes
Ex. 10	0.43	0.55	0.50	0.071	4.00	15.50	2.80	4.10	0.009	0.007	-	0.62	Yes
Ex. 11	0.35	0.80	1.98	0.022	0.08	0.03	0.08	0.04	0.12	0.008	-	-	Yes
Ex. 12	0.54	0.77	0.80	0.082	0.06	0.03	0.04	0.005	0.06	0.03	Al: 0.031	-	Yes
Ex. 13	0.42	0.68	1.01	0.040	0.08	0.10	0.03	0.31	0.03	0.004	-	-	Yes
Ex. 13*	0.42	0.68	1.01	0.040	0.08	0.10	0.03	0.31	0.03	0.004	-	-	No
Comp. Ex. 1	0.07	0.60	0.41	0.220	3.94	16.60	3.00	0.31	0.008	0.005	-	0.63	No
Comp. Ex. 2	0.07	0.60	0.41	0.290	3.94	16.60	3.00	0.31	0.007	0.005	-	0.63	Yes
Comp. Ex. 3	0.55	0.55	0.48	0.310	4.07	16.30	3.00	0.30	0.008	0.004	-	1.13	No
Comp. Ex. 4	0.18	0.58	0.48	0.408	6.54	16.30	3.00	1.50	0.007	0.008	-	1.01	No
Comp. Ex. 5	0.32	0.85	1.23	0.210	0.04	0.03	0.03	0.08	0.01	0.011	-	-	Yes
Comp. Ex. 6	0.57	0.55	1.75	0.209	0.03	0.03	0.03	0.005	0.05	0.013	-	-	Yes
Conv. Ex. 1	3.70	2.23	0.35	0.006	0.03	0.02	0.67	-	-	-	Mg: 0.042	3.70	No
Conv. Ex. 2	0.41	0.65	1.17	0.030	0.10	0.11	0.11	-	0.08	-	-	0.43	Yes

Note: (1) "Comp. Ex." means Comparative Example, and "Conv. Ex." Means

Conventional Example.

* No heat treatment was conducted.

[0046]

(Analysis of sulfide matrixes)

A test piece cut out of each sample of Examples 1-13*, Comparative Examples 1-6 and Conventional Examples 1 and 2 was embedded in a resin, ground with emery papers to #1000, further ground with diamond particles of 15 μm, 9 μm, 3 μm and 1 μm, respectively, and finish-ground with colloidal silica successively. An area ratio of sulfides containing at least one of Mn and Cr, and a ratio of the number of sulfides each having a circularity of 0.7 or more to the total number of sulfides were measured. Also, a matrix microstructure and an austenite ratio were examined.

[0047]

Using an image analyzer (IP-1000, available from Asahi Kasei Corp.), the area ratio (%) of sulfides and an average equivalent-circle diameter (μm) were measured with respect to the sulfides corresponding to circles of 1.0 μm or more in diameter in the whole field of vision at a magnification of 200 times. The same test piece as above was observed by the image analyzer to get an image of each sulfide, from which the circularity of sulfides was calculated using the formula of $(4 \times \pi \times \text{area of sulfide}) / (\text{peripheral length of sulfide})^2$. The results are shown in Table 2. The relation between an area ratio (%) of the sulfides and a ratio (%) of the number of sulfides having a circularity of 0.7 or more to the total number of sulfides is shown in Fig. 3. The volume ratio (%) of an austenite (γ ratio) was measured using an X-ray stress analyzer (STRAINFLEX MSF-2M, available from Rigaku).

[0048]

Table 2
Results of Sulfide Measurements

No(1)	Area Ratio of Sulfides (%)	Percentage of Sulfides Having Circularity ≥ 0.7 (%)(2)	Matrix Microstructure	γ Ratio (%)
Ex. 1	0.2	86.4	M, δ, γ, (Cr, Mn)S	6.2
Ex. 2	0.5	95.5	M, δ, γ, (Cr, Mn)S	6.5
Ex. 3	0.8	88.6	M, δ, γ, (Cr, Mn)S	6.6
Ex. 4	1.2	82.2	M, δ, γ, (Cr, Mn)S	7.5
Ex. 5	3.0	70.2	M, δ, γ, (Cr, Mn)S	8.2
Ex. 5*	2.9	70.4	M, δ, γ, (Cr, Mn)S	9.8
Ex. 6	1.0	88.9	M, δ, γ, (Cr, Mn)S, NbC	12.0
Ex. 7	0.9	92.5	M, δ, γ, (Cr, Mn)S, NbC	10.0
Ex. 8	1.0	87.7	M, δ, γ, (Cr, Mn)S, NbC	28.8
Ex. 9	0.8	81.0	M, δ, γ, (Cr, Mn)S, NbC	5.8
Ex. 10	1.1	88.0	M, δ, γ, (Cr, Mn)S, NbC	6.6
Ex. 11	0.2	85.1	α, P	0.0
Ex. 12	1.1	88.2	α, P	0.0
Ex. 13	0.6	90.0	α, P	0.0
Ex. 13*	0.6	88.9	α, P	0.0
Comp. Ex. 1	2.8	66.7	M, δ, γ, (Cr, Mn)S	8.7
Comp. Ex. 2	3.1	65.0	M, δ, γ, (Cr, Mn)S	11.0
Comp. Ex. 3	3.3	61.3	M, δ, γ, (Cr, Mn)S	96.0
Comp. Ex. 4	3.8	58.9	M, δ, γ, (Cr, Mn)S	33.1
Comp. Ex. 5	3.1	63.3	α, P	0.0
Comp. Ex. 6	3.2	62.6	α, P	0.0
Conv. Ex. 1	0.0	-	α, P, Graphite	0.0
Conv. Ex. 2	0.7	54.0	α, P	0.1

Note: (1) "Comp. Ex." means Comparative Example, and "Conv. Ex." means Conventional Example.

(2) A ratio of the number of sulfides having a circularity of 0.7 or more to the total number of sulfides.

* No heat treatment was conducted.

α, δ: Ferrite, γ: Austenite, M: Martensite, P: Pearlite

[0049]

As is clear from Table 2 and Fig. 3, Examples 1-13* of the present invention has an area ratio of sulfides is 0.2-3.0%, and a ratio of the number of sulfides each having a circularity of 0.7 or more to the total number of sulfides is 70% or more. On the other hand, Comparative Examples 1-4 of stainless steel and Conventional Samples 5-6 of Carbon Steel have an area ratio of sulfides exceeding 3.0% except Comparative Example 1 and their number of sulfides each having a circularity of 0.7 or more to the total number of sulfides are less than 70% including Comparative Examples. Comparative Examples 3 and 4 has an austenite ratio of 30% or more. Conventional Example 1 has no sulfide in the matrix microstructure thereof. Conventional Example 2 has an area ratio of sulfides of 0.7% but its number of sulfides each having a circularity of 0.7 or more to the total number of sulfides is 75%.

[0050]

(High-temperature yield strength, high-temperature rigidity, and linear thermal expansion coefficient)

According to "High Temperature Tensile Test Method of Steel and Heat-Resistant Alloys" of JIS G 0567, a II-10 test piece cut out from each sample of Examples 1-13*, Comparative Examples 1-6 and Conventional Examples 1 and 2 was measured with respect to 0.2-% yield strength (MPa) at 350°C, 450°C and 500°C, respectively.

[0051]

High-temperature rigidity was evaluated as a Young modulus at 350°C, 450°C and 500°C. Thus, a planar test piece of 1.5 mm x 10 mm x 60

mm, whose entire surface was ground, was produced from each sample as a test piece for measuring high-temperature rigidity, according to JIS Z 2280, "Method of Testing High-Temperature Young's Modulus of Metal Materials." Each test piece was placed in a furnace at 350°C, 450°C and 500°C, respectively, in the atmosphere, and vibrated by a free-vibration electrostatic driving method to detect a vibration resonance frequency, from which a Young's modulus was calculated.

[0052]

A test piece machined to a diameter of 5 mm and a thickness of 20 mm was measured with respect to thermal expansion between room temperature and 500°C at a temperature-elevating speed of 3°C/minute in the atmosphere using a thermomechanical analyzer (THEMOFLEX TAS-200 TAS8140C, available from Rigaku). Low thermal expansion properties were evaluated with respect to an average linear thermal expansion coefficient (x 10^{-6}/3°C) between room temperature and 500°C. For this purpose, a test piece machined to a diameter of 5 mm and a thickness of 20 mm was measured with respect to thermal expansion by heating at a temperature-elevating speed of 3°C/minute in the atmosphere using a thermomechanical analyzer (THEMOFLEX TAS-200 TAS8140C, available from Rigaku) provided with a detection stick made of molten quartz and a support pipe. The evaluation results of three properties above are shown in Table 3.

[0053]

(Thermal cracking resistance)

Using a thermal cracking test machine 40 schematically shown in Fig. 4, a thermal cracking resistance test was conducted. The thermal cracking test machine 40 comprises a vertically movable water bath 41 for storing a cooling water 42, a high-frequency oscillator 43, a high-frequency-oscillating coil 44 connected to the high-frequency oscillator 43, a rod 46 having a tip end, to

which a test piece 47 was attached, a shaft 45 rotatably supporting the rod 46, a thermocouple 48 attached to the test piece 47, and a recorder 49 of temperature data connected to the thermocouple 48, the test piece 47 being machined to a diameter of 90 mm and a thickness of 50 mm. After repeating a heating-cooling cycle (5 seconds) 1000 times, which comprised a step that a surface of the horizontally kept test piece 47 was heated to 450°C by the high-frequency-oscillating coil 44, a step that after the test piece 47 was swung downward, the water bath 41 was elevated as indicated by a dotted line, so that the test piece 47 was rapidly cooled by the room-temperature cooling water 42, and a step that the water bath 41 was moved downward, and the test piece 47 was returned to the original horizontal state, the test piece was measured with respect to the maximum crack length (μm) in its cross section as an index of thermal cracking resistance. The evaluation standards of the thermal cracking resistance are as follows:

Excellent (◎): The maximum crack length was 50 μm or less.

Good (○): The maximum crack length was 100 μm or less.

Fair (△): The maximum crack length was more than 100 μm and 150 μm or less.

Poor (×): The maximum crack length was more than 150 μm.

The results are shown in Table 3.

[0054]

As is clear from Table 3, all of Examples 1-13* of the present invention has the maximum crack length of 98 μm or less and are significantly excellent in the thermal cracking resistance with respect to Comparative Examples 1-6 having 110-179 μm and Conventional Examples 1 and 2 each having 325 μm and 121 μm, respectively. Moreover, Examples 1-10 have a 0.2-% yield strength (MPa) of 350 MPa or more even in the minimum value in a temperature range of 350°C to 500°C, and a Young's modulus of 154 GPa or

more even in the minimum value. In addition, an average linear thermal expansion coefficient between room temperature and 500°C is as low thermal expansion of 11.5-12.8 x 10^{6}/°C between room temperature and 500°C, which is substantially equal to that of a cylinder liner made of flake graphite cast iron (13.1 x 10^{-6}/°C in a temperature range of 20-480°C).

[0055]

As is clear from the foregoing, Examples 1-13* are excellent in the thermal cracking resistance with respect to those of Comparative Examples and Conventional Examples. Particularly, in Examples 1-10 using the δ-M cast steel, the 0.2-% yield strength (MPa) is 350 MPa or more and the Young's modulus as an indicator of high-temperature is 154 GPa or more in a temperature range of 350°C to 500°C. In addition, an average linear thermal expansion coefficient between room temperature and 500°C is a low of thermal expansion of 11.5-12.8 x 10^{6}/°C between room temperature and 500°C, which is superior to those of Comparative Examples 1-4 and Conventional Examples 1 and 2.

[0056]

The evaluation of the necessity for the heat treatment is as follows. When Examples 5 and 13 describing test pieces cut out of the sample, which are subjected to the heat treatment of the present invention after casting, are compared with Examples 5* and 13* describing test pieces cut out of the sample having the same composition as Examples 5 and 13, which are not subjected to the heat treatment after casting, the Examples 5 and 13 subjected to the heat treatment show decrease a little in the maximum crack length, thereby showing the improvement of the thermal cracking resistance.

[0057]

Table 3

Evaluation Results of High-temperature yield strength, High-temperature rigidity, Thermal cracking resistance and Linear thermal expansion coefficient

No[1]	0.2-% Yield Strength (MPa) at			Young's Modulus (GPa)			Thermal Cracking Resistance		α[3] (x 10^{-6}/°C)
	350°C	450°C	500°C	350°C	450°C	500°C	Max.[2] Crack Length (μm)	Evaluation	
Ex. 1	781	721	622	195	182	161	33	◎	12.1
Ex. 2	766	684	601	190	175	160	25	◎	12.5
Ex. 3	673	621	548	195	177	155	35	◎	12.1
Ex. 4	688	611	534	190	177	154	42	◎	12.8
Ex. 5	531	455	358	188	174	160	85	◎	12.5
Ex. 5*	534	471	366	187	174	162	97	○	12.5
Ex. 6	531	455	358	190	177	156	31	◎	11.8
Ex. 7	661	610	544	195	170	155	20	◎	11.6
Ex. 8	686	623	545	193	177	155	54	○	12.5
Ex. 9	677	633	541	193	175	165	26	◎	12.6
Ex. 10	645	611	533	190	178	158	44	◎	11.5
Ex. 11	411	366	301	195	173	155	89	○	12.8
Ex. 12	455	368	305	195	172	154	93	○	13.1
Ex. 13	450	374	310	194	172	155	87	○	12.6
Ex. 13*	410	322	298	193	168	154	98	○	12.4
Comp. Ex. 1	671	610	510	169	158	138	162	×	11.5
Comp. Ex. 2	665	606	503	171	155	136	179	×	12.5
Comp. Ex. 3	446	437	398	162	154	132	110	△	18.0
Comp. Ex. 4	512	468	432	164	156	135	122	△	17.2
Comp. Ex. 5	398	311	288	191	169	154	141	×	12.5
Comp. Ex. 6	470	388	312	195	176	148	156	×	12.6
Conv. Ex. 1	411	358	245	175	160	135	325	×	13.1
Conv. Ex. 2	449	377	303	194	174	155	121	△	14.0

Note: (1) "Comp. Ex." means Comparative Example, and "Conv. Ex." means Conventional Example.

(2) Max. Crack Length means Maximum Crack Length.

(3) Average linear thermal expansion coefficient between room temperature and 500°C

* No heat treatment was conducted.

[0058]

Examples

Fig. 1 shows a cross-sectional view of the piston 10 of Examples of the present invention. This piston 10 comprised a head portion 11, a skirt portion 12, a cooling hollow portion 13, a pin boss portion 14, a pin-engaging inner surface 14d, a combustion chamber 15, a top surface 16, a lip 17, a top land 18, and ring grooves 19. 10h denotes a compression height, and D denotes an external diameter. To obtain the composition of Example 2, a cast steel was melted in a 100-kg, high-frequency furnace with a basic lining, poured into a ladle at 1550°C or higher, and immediately poured into a sand mold having a cavity having a shape of the piston shown in Fig. 1 at sand mold having a cavity having a shape of the piston shown in Fig. 1 at 1500°C or more. To reduce its weight, main portions of the piston 10 had an average thickness of 3.0 mm or less after the completion thereof. Conducted after casting was a solution treatment comprising holding the cast steel at 1040°C for 1 hour and then rapidly cooling it, and then an aging treatment comprising holding it at 600°C for 4 hours and then air-cooling it. The resultant piston 10 was cut and ground in its outer periphery. Fig. 2 is a photomicrograph (magnification: 400 times) showing the metal microstructure of the composition of Example 2. The area ratio of ferrite to martensite was 92.3%. In addition, casting defects to cause problems did not occur in the casting step, neither did troubles such as poor cutting, the abnormal wear of tools, etc. occur in the machining step. The resultant pistons 10 were assembled in a test apparatus which imitates 10,000-cc, 6-cylinder diesel engine, to conduct a durability test. Although the temperature

dependent from the piston 10 in all the loads was 480°C, it was confirmed that the resultant piston 10 had not only high-temperature yield strength, high-temperature rigidity, thermal cracking resistance and low thermal expansion properties but also the resistance to thermal load and mechanical load when used in a temperature range from room temperature to 450-500°C.

[0059]

Effects of the Invention

As described above in detail, the internal engine piston of the present invention has high-temperature yield strength, high-temperature rigidity, thermal cracking resistance and low thermal expansion properties when used in a temperature range from room temperature to 450-500°C, and provides an internal engine piston suitable for automobile engines, particularly for diesel engines and a method for producing such an internal engine piston.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a cross-sectional view showing the piston 10 of Examples of the present invention;

Fig. 2 is a photomicrograph (magnification: 400 times) showing the metal microstructure of the piston 10 of Example 2 of the present invention;

Fig. 3 is a figure showing the relation between an area ratio (%) of the sulfides and a ratio (%) of the number of sulfides having a circularity of 0.7 or more to the total number of sulfides;

Fig. 4 is a schematic view showing a thermal cracking test machine 40;

Fig. 5 is a cross-sectional view showing a conventional piston 20 comprising separately produced head portion and skirt portion, the head portion comprising a pin boss portion, and integrally assembled;

Fig. 6 is a photomicrograph (magnification: 100 times) showing the

metal microstructure of a conventional piston made of forged steel; and

Fig. 7 is a cross-sectional view showing a conventional piston 30 comprising separately produced head portion, skirt portion and a pin boss portion and integrally connected.

Descriptions of Letters and Numerals

10, 20, 30: Piston (internal engine piston);

10h, 20h, 30h: Compression Height;

11, 21, 31: Head Portion;

12, 22, 32: Skirt Portion;

13, 23, 33: Cooling Hollow Portion;

14, 24, 34: Pin Boss Portion;

14d: Pin-engaging Inner Surface;

15, 25, 35: Combustion Chamber;

16, 26, 36: Top Surface;

17, 27, 37: Lip;

18, 28, 38: Top Land;

19, 29, 39: Ring Grooves;

40: Thermal Cracking Test Machine;

41: Water Bath;

42: Cooling Water;

43: High-frequency Oscillator;

44: Coil;

45: Shaft;

46: Rod;

47: Test Piece;

48: Thermocouple;

49: Recorder;

D: External Diameter;

a: Inclusions; and

f: Cover.

Drawings

Fig. 1

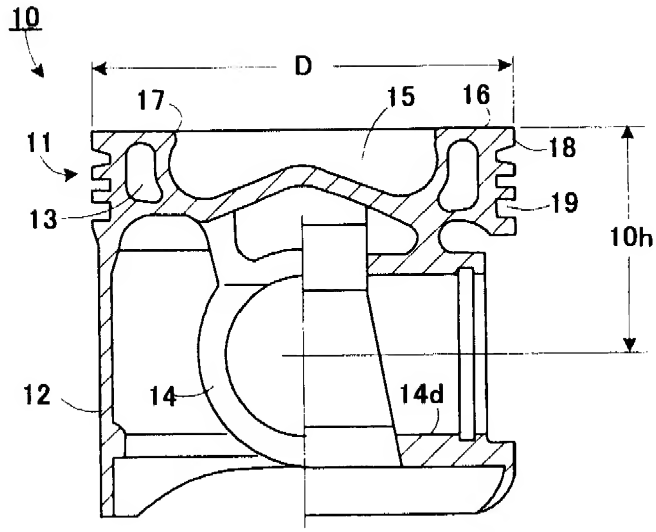


Fig. 2

Fig. 3

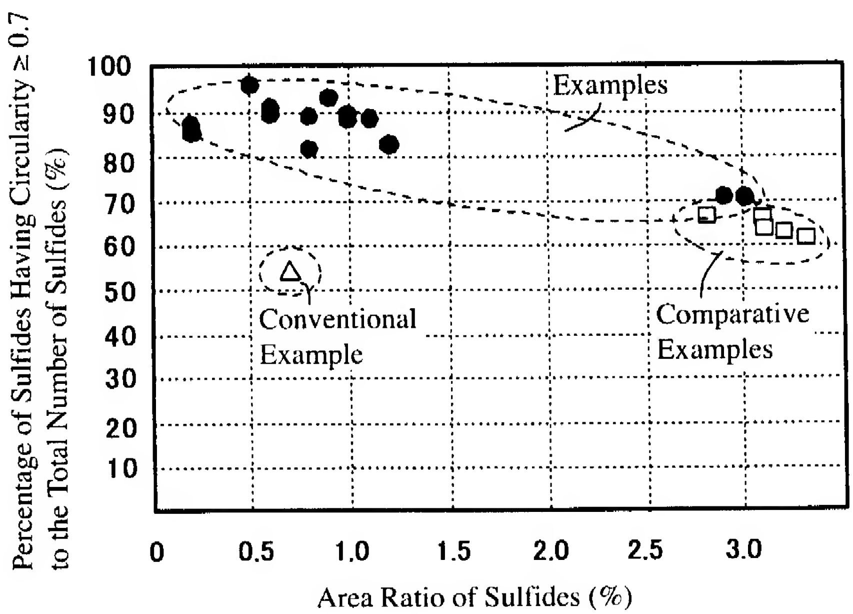

Percentage of Sulfides Having Circularity ≥ 0.7 to the Total Number of Sulfides (%)
100
90
80
70
60
50
40
30
20
10
0
0.5
1.0
1.5
2.0
2.5
3.0
Area Ratio of Sulfides (%)
Examples
Conventional Example
Comparative Examples

Fig. 4

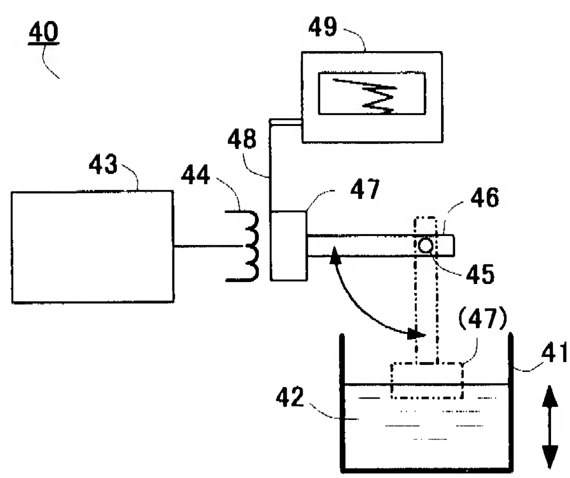

40
49
48
43
44
47
46
45
(47)
41
42

Fig. 5

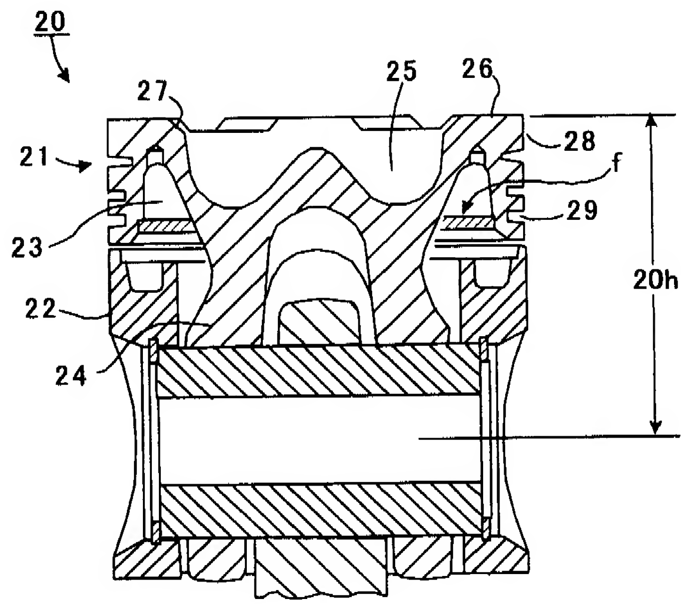


Fig. 6

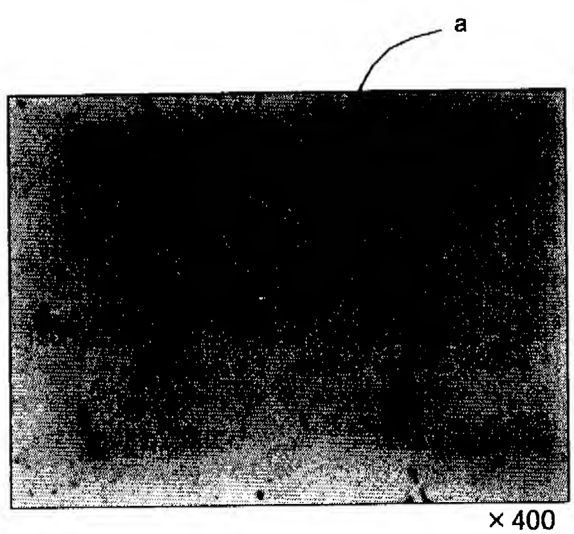
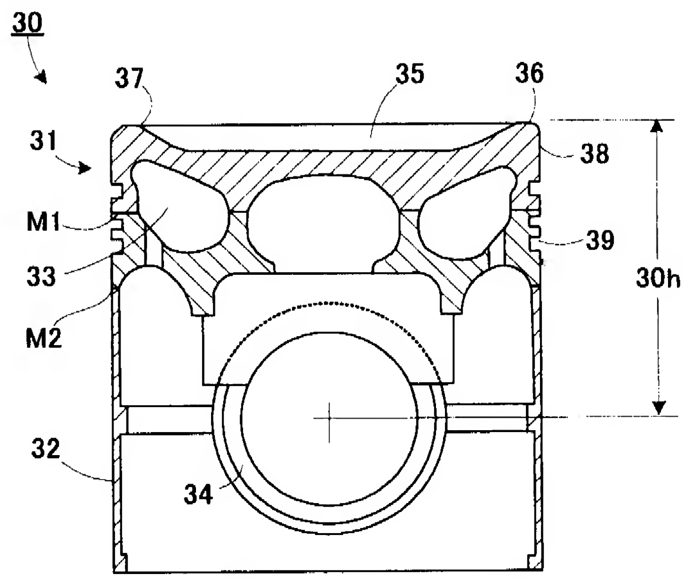


Fig. 7



Japanese Patent Application No. 2003-097015

Abstract

Problems to be solved by the Invention:

To provide an internal engine piston having high high-temperature yield strength, high-temperature rigidity, thermal cracking resistance and low thermal expansion properties such that it can be used in a temperature range from room temperature to 450-500°C suitable for automobile engines, particularly for diesel engines, etc.

Solution:

An internal engine piston comprising a cast steel and formed by integral casting including main constitutional components of the piston such as a head portion, a pin boss portion and a skirt portion, and further additionally including a cooling hollow portion, wherein the cast steel has an area ratio of sulfides containing at least one of Mn and Cr is 0.2-3.0% in said cast steel microstructure, and wherein a ratio of the number of sulfides each having a circularity of 0.7 or more to the total number of sulfides is 70% or more.

Selected Drawings: Fig. 1